PROJECT DOCUMENTATION

2nd Advisory Board
HIGHLIGHT REPORT

A high level summary update of TEAM-A's KPI achievement since the programme's beginning. Further detail will be provided upon request and during Advisory Board meetings.

Project: The Tailored Electromagnetic Materials Accelerator (TEAM-A)

Release: 1
Date: 30th July 2021
Period Covered: Beginning of programme – July 2021
Author: JPHayes
Owner: TEAM-A Leadership Board
Document Ref: 0044.1_UD2
Version No: V1-0

1 Highlight Report History

1.1 Document Location

This document is only valid on the day it was printed.
The source of the document will be found at this location – TEAM-A SharePoint > Shared Documents > *0044: Advisory Board > 0044.1_UD2.* Contact the TEAM-A administration for access.

1.2 Revision History

Date of this revision: 30/07/21
Date of next revision: Aug 2022

Revision date	Previous revision date	Summary of Changes	Changes marked
		First issue	

1.3 Approvals

This document requires the following approvals.

Name	Signature	Title	Date of Issue	Version
TEAM-A Leadership Board				1

1.4 Distribution

This document has been distributed to:

Name	Date of Issue	Version
Prof. Geoff Nash	29.07.21	1
Prof. Chris Lawrence		1
Josie Butcher In place of Michelle Spillar		1
Dr Richard Bryant		1
Alison Cooke In place of Francesca Riches		1
Jade Hayes		1
Prof. Andrew Jones in place of Mark Goodwin		1
Dr Benny Hallam		1
Prof. Sajad Haq		1
Laura Cadman In place of Jessica Bonham		1

2 Table of Contents

3 Programme Achievements

Summary: This five-year Prosperity Partnership programme builds upon the successful relationship that exists between the University of Exeter and QinetiQ. TEAM-A is developing advanced materials that can be used to control and manipulate the propagation of electromagnetic and acoustic energy in a highly tailored, bespoke fashion, and focuses to develop innovative techniques for their cost-effective manufacture, thereby working to bolster academia and the technology sector within the South-West of England. The aim of TEAM-A is to create a sustainable, long term partnership, underpinned by revenue created through the licensing of intellectual property, the development of products and the advancement of academic understanding.

Advancement of academic understanding and technology development:

TEAM-A consists of a portfolio of projects that aim to exploit our comprehensive interdisciplinary capabilities to deliver a number of ground-breaking technologies. The case studies below, and those mentioned in previous years, demonstrate TEAM-A's industry leading and academic excellence, and show how this is translating into outputs such as scientific publications, patents, technology and staff development. A critical objective over the next few years is to establish further partnerships to provide routes to technology exploitation.

Multispectral Imaging: Multispectral imaging finds applications in a host of important fields, from security and defence to environmental monitoring, agriculture, remote sensing, and medical diagnostics. Current multispectral systems are limited in speed and resolution, and TEAM-A is developing new approaches to overcome these limitations, making multispectral imaging faster, cheaper and more effective. This work therefore has the potential for significant economic and societal impact. In particular, we are developing approaches that combines the extraordinary optical transmission (EOT) effect and chalcogenide phase-change materials (PCMs) to deliver dynamically tuneable image capture in the mid and long-wave infrared region of the spectrum. The principal of tuneable filter operation has also been experimentally demonstrated by ex-situ switching (thermal annealing) of EOT filters containing PCMs, an important milestone in the development of reliable and repeatable fabrication and testing procedures for such filters, which are a key enabling technology in advanced multispectral imaging systems.

Terahertz Imaging and Modulators: We have designed what we believe to be the most efficient mm-wave photomodulator to date, which will allow us to create fast and efficient components that can be used for high speed communications and terahertz (THz) imaging. One application we are focusing on is passive THz imaging in the far-field for security, which will allow us to take images in the THz regime without using a THz source, only detecting the faint THz radiation emitted by warm bodies. This would speed up security imaging in airports and other public places, with economic and societal impacts. We are also working on using our near-field imaging system for measuring the thickness of healthy tissue around breast tumours that have been surgically removed (see Figure 1), which will hopefully lead to reductions in the number of surgeries required, saving money, and reducing local recurrence of cancer, saving lives. This work therefore directly addresses the Healthy Nation component of EPSRC's Prosperity Outcomes Framework. To enable future commercialisation, we have filed patent applications relating to the methods and apparatus for imaging an object comprising biological material: GB1908140.5 filed, 7th June 2019, and GB2003820.4 filed 17th March 2020.

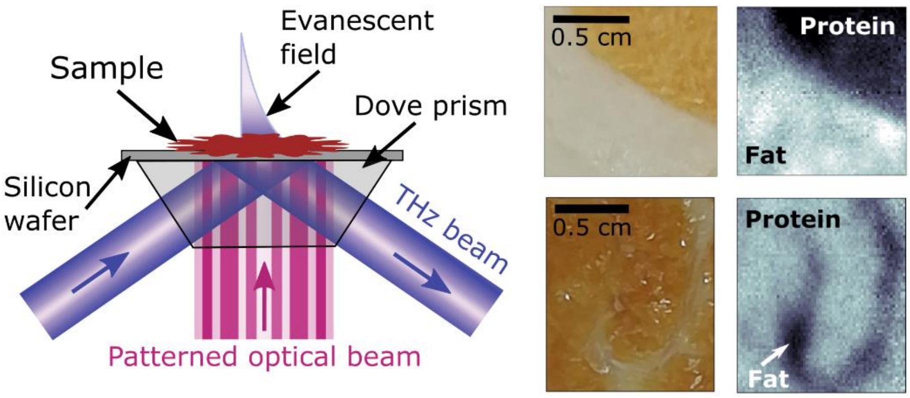

Figure 1: Schematic diagram (left-hand-side) illustrating use of a beam of terahertz radiation for the imaging of biological systems (right-hand-side)

Phased-arrays of Thermophones: Thermophones are novel acoustic sources, which convert periodic heating of a thin metallic film into sound, that have the potential to be flexible, transparent, broadband, and physically robust (no moving parts). They could therefore replace traditional sources in a wide range of applications. Recently, in the first work of its kind, we have demonstrated that phased arrays of thermophones can be used to control the shape and direction of the sound field they produce. In contrast to conventional phased array sound sources, thermophone phased arrays are cheap and simple to manufacture, have a wide frequency range, have few scale constraints, and have no mechanical coupling by virtue of the fact that the sources do not move (they produce sound directly from heat). The coupling produces a new type of controllable sound source of its own that can be used to simplify phased array design. We show that if we combine this coupling with constrictions in the flow of electrical current, we can create a fully controllable phased array from a single thin metal film. This radical new design of phased array offers a new way to construct simple, cheap phased arrays from sustainable materials, and we are now seeking partners to take this work forward.

Additive Manufacturing: The research that we are performing at the Centre for Additive Layer Manufacturing (CALM) at the University of Exeter, as apart of TEAM-A has the potential to have a significant impact on the AM industry. The selective multi-material printing that we are developing, with the ability to align fibrous filler in situ during the printing process, is an extremely attractive proposition for the fabrication of many products. This in itself has many added benefits, including the ability to create novel and bespoke components that can provide shielding against interference signals, which is of growing concern in the consumer market, as well as in more specialized areas such as medicine, aviation, military and defence.

Collaborations:

We continue to collaborate with a wide range of partners, including those shown above. New collaborations, and important updates to existing partnerships, include:

The Centre for Metamaterial Research and Innovation: has recently been established in Exeter, with support from a wide range of academic and industrial partners. Our association with this Centre allows us to tap into a wide range of additional collaborators, supporting our aim of making TEAM-A a sustainable partnership beyond 2022.

National Science Foundation Industry-University Cooperative Research Center for Metamaterials (CfM) in the USA: A number of researchers from TEAM-A, including Professors Oana Ghita, Alastair Hibbins, Geoff Nash and David Wright are part of a new collaboration formed with this leading centre in the US**.** This new collaboration resulted in a successful outline proposal being submitted to the EPSRC call for International Centre-to-Centre Research Collaborations. In particular, the aforementioned work regarding THz imaging and modulators has directly resulted in the choice of one of the three research strands in this collaboration, which will fund Dr Hooper and Prof Hendry beyond the life of the current TEAM-A project, and maintain links to QinetiQ.

CSIC Madrid (Prof. Jan Siegel): There is potential to collaborate with the group of Prof Jan Siegel at CSIC Madrid on upscaling the fabrication of EOT arrays using direct laser writing techniques (which are many orders of magnitude faster in terms of fabrication as compared with the e-beam lithography techniques used as present). This would be an important step in demonstrating that this technology could be manufactured cost effectively.

Other Collaborations: Other ongoing collaborations include those with the University of Edinburgh (discussions relating to further Orbital Angular Momentum studies), Royal Devon and Exeter NHS Trust (support for the THz medical imaging work), and Technical Composites Ltd (with whom we wish to work on metamaterial radome designs). Early-stage discussions are underway with Power Roll Ltd (Home | Power Roll), a new SME who hold a novel solar cell technology.

4 KPI Status Summary

Please contact TEAM-A administration to see 0045_TEAM-A Impact Exploitation Plan_V2 & TEAM-A_Benefits Realisation v1 for a detailed account of TEAM-A's KPIs & considered benefits realisation.

KPI	Detail of Output
Scientific Excellence	
Peer-reviewed papers published/submitted	13 papers published, 2 submitted for review and 25 in development. Not including all additional conference papers submitted. Our published papers include: 1. I. R. Hooper, L. E. Barr, S. M. Hornett, E. Hendry, N. E. Grant, J. D. Murphy. 'High Efficiency THz and RF Photomodulators". Scientific Reports. 2. L. E. Barr, P. Karlsen, S. M. Hornett, I. R. Hooper, M. Mrnka, C. R. Lawrence, D. B. Phillips, E. Hendry. 'Super-resolution imaging for sub-IR frequencies based on total internal reflection'. Optica. 3. L. E. Barr, I. R. Hooper, D. B. Phillips, C. R. Lawrence, E. Hendry. 'Efficient mm-wave photomodulation via coupled Fabry-Perot cavities'. Journal of Applied Physics. 4. J.K. Hamilton, S. J. Berry, J.H. Spencer, C.R. Lawrence, T.D. Drysdale. 'Three-dimensional profiling of collimated radio-frequency orbital angular momentum beams'. IET Microwaves, Antennas & Propagation. 5. M. Baraclough, S. S. Seetharaman, I. R. Hooper, W. L. Barnes. 'Microwave metamaterial analogues of molecular aggregates'. Nature Materials. 6. D. Matsunaga, J.K. Hamilton, F. Meng, N. Bukin, F. Y. Ogrin, J. M.

	Yeomans, and R. Golestania. ‘Controlling collective rotational patterns of magnetic rotors’. Nature Communications. 7. J. G. Beadle, I. R. Hooper, J. R. Sambles, A. P. Hibbins. ‘Broadband, slow sound on a glide-symmetric meander-channel surface’. Journal of. The Acoustical Society of America. 8. A. W. Powell, J. Ware, J. G. Beadle, D. Cheadle, T. H. Loh, A. P. Hibbins, and J. R. Sambles. ‘Strong, omnidirectional radar backscatter from subwavelength, 3D printed metacubes’. IET Microwaves, Antennas & Propagation. 9. M. Baraclough, I. R. Hooper, W. L. Barnes. ‘Investigation of the coupling between tunable split-ring resonators’. Physical Review B. 10. S. S. Seetharaman, B. Tremain, W. L. Barnes, I. R. Hooper. ‘Realizing an ultra-wideband backward-wave metamaterial waveguide’. Physical Review B. 11. P. S. Keatley, E. R. Glover, B. Tremain, I. R. Hooper, A. P. Hibbins, R. J. Hicken. ‘A Ferrite-Filled Cavity Resonator for Electronic Article Surveillance on Metallic Packaging’. IEEE Transactions on Magnetics. 12. M. Baraclough, I. R. Hooper, W. L. Barnes. ‘Direct Observation of Defect Modes in Molecular Aggregate Analogues’. Physical Review B. 13. J. K. Hamilton, I. R. Hooper, C. R. Lawrence. ‘Absorption Modes of Möbius Strip Resonators’. Sci. Rep.
Conferences/seminars attended	Due to the global pandemic of 2020 we were unable to attend and present at any conference; however, online substitutes were attended where appropriate. Overall, 11 conferences have been attended to present posters and demonstrations, this does not include conferences attended to network and learn. 1 trade show and 3 public lectures, including Café’ Scientifique. Despite the difficulties presented by COVID in 2020, many of our Research Fellows were invited to attend virtual residential events and meetings. For example, Exeter Scholars virtual residential week, where students attended a series of talks and workshops. L.Barr gave a lecture on computational THz imaging, and chaired a session of talks by the students on their research projects. Many of our Research Fellows have also been invited to give oral presentations, including at the IRMMW-THz meeting.
Research proposals supported	3 successful proposals supported, Prof. Euan Hendy of the University of Exeter “Computational spectral imaging in the THz band” (£234k). Prof. Alastair Hibbins, 2x NATEP & TCL - National Aerospace Technology Exploitation Programme

	(NATEP), Composite Baseplates for Aerospace Antennas (£40.404k) & High functionality, low cost, small composite antennas (£22,220k).
Collaboration	The global pandemic of 2020 onwards has largely impacted our ability to work together physically, as travelling to our partner sites were restricted. Nonetheless we have exchanged the following and each of our QQ based Research Fellows have received specialist training on QQ unique equipment, enhancing their capabilities and bridging the gap between academia and industry skills.
Talks/presentations at partner sites	23 presentations were attended, including wider QinetiQ tech talks and networking events. Many of our CO-I's and PDRFs have presented or attended QQ based Tech Talks. 2 Customer focus groups hosted by The University of Exeter and many online based customer problem solving exercises.
Exchange of equipment	RF surface wave launcher – Borrowed from Exeter to support a MOD-funded project at QinetiQ (QQ). Work completed, enabling QQ to calibrate their equipment and test ideas relating to how surface currents can influence radar cross-section. THz source – Lent to Prof Euan Hendry and now used in the far-field THz scanner that is being developed under TEAM-A (RP2.2). Saved the project ~£20k in material costs (the price of a new THz source). THz material characterisation work – Dr Emma Newton at QQ has been trying to develop new materials for THz control, but lacked equipment to characterise their electromagnetic properties. Access to Exeter's facilities (owned by Prof Euan Hendry) with assistance from experienced users (Dr Lauren Barr) enabled Dr Newton to assess the materials, providing valuable input to QQ's materials strategy and saving the expense of setting up a new facility (an issue of both time and money). Transmission Electron Microscope (TEM) – Dr Layla Malouf of QQ utilised Exeter's Living System's Institute to analyse nanoparticle distributions in brittle polymers. Here Exeter also advised on how to prepare and microtome samples, saving QQ research time and the cost of purchasing a TEM. Thermal cameras – Two of the current TEAM-A projects based at Exeter (RP2.1, RP3.5) involve the use of fast heat pulses in '2D materials' such as graphene. In particular, the IR beacons of RP2.1 are based around the use of high frequency pulses of radiation to enable coded identification signals. Whilst Exeter have access to thermal imagers, instruments capable of fast framerate (50Hz plus) measurements are lacking: as these are expensive and specialised. QQ possess

Exchange of staff	such cameras – both long- and short-wave – and in 2019 QQ transported them to Exeter for a day to support the project. This proved highly useful and saved Exeter £200k+ (the cost of the equipment). RC3 – Prof Oana Ghita's (UoE) advice to the Acoustic Materials team at QQ re: printed elastomers – A discussion as to the feasibility of printing elastomeric materials to support customer requests for coating manufacture. Several visits and phone calls made, introducing Prof Ghita and Dr Maria Mann (PDRF) to the team at QQ. The main summary is: the materials can be printed but the scale required (100s of square metres from foot-square samples) would be difficult to meet at present; however, designs could usefully be tested before mass production via expensive moulds; Exeter do not have suitable facilities but can act as advisors to find appropriate suppliers and assess their offerings; this will be pursued in future months, as part of a larger customer project that is still under discussion. RC1 – Prof Oana Ghita's (UoE) advice to the RF Materials team at QQ re: printed RF attenuators – Following successful discussions, this has become the main thrust of RP5.1, with samples made at Exeter being tested (mechanically and electromagnetically) at QQ. Dr Shahid Hussain is the resident expert on the requirement, and has hence become the QQ CO-I for RP5. RC2 - Rupert Anderton's (QQ) advice to the THz research – Rupert Anderton has provided input and support to RP2-2, particularly regarding advice on the requirements for a THz scanner, and has subsequently provided letters of support for Prof Hendry's recently successful research proposal "Computational spectral imaging in the THz band".
Commercial Activities Industrial Engagement	PepsiCo: Totalled to three projects and £177,280 of investment from PepsiCo which concluded in June 2020 (Commercially Sensitive): ○ "Digitization of Snacking" – COMMERCIALLY SENSITIVE - Project based at Exeter, supporting a new Research Fellow. ○ Microwave oven design – COMMERCIALLY SENSITIVE – Project based at QQ, providing equipment that will enable the characterisation of the output of the first project ○ RF Spectroscopy – using unique equipment based at QQ Farnborough,

	Dr Joshua Hamilton (PDRF) is characterising foodstuffs relevant to PepsiCo's business interests, over a far broader range of temperatures and frequencies than was previously published and practical. Two papers planned. Discussions for future collaborations are ongoing. Technical Composites Ltd: Following an introduction from Profs Hibbins and Sambles (UoE), we have successfully secured two NATEP proposals with Mike Sloan (ManDir). The first relates to the development of a joint QQ/UoE patent on RF filters into a radome material; the other relates to new magnetic materials for aerospace applications. In the first round of reviews both were marked highly, although the former requires development to a demonstrator (to be undertaken in RC1). The other is proceeding to final review, with the intention of it being undertaken within TEAM-A if it is funded. RFID opportunity (COMMERCIALLY SENSITIVE): a high-street retailer has been discussing RFID challenges with Prof Hibbins, leading to TEAM-A being invited into the discussions to draw upon QQ expertise in the setting up of complete RFID systems. This has been paused due to the customer lacking the funds to pursue this before the new financial year (Apr20 onwards). Bank of England: We have recently registered our interest in bidding for work with the Bank via DASA proposals (https://www.gov.uk/government/news/market-exploration-innovative-security-features-for-bank-notes). This follows a face-to-face meeting last year (2018), proposing that TEAM-A offers a route to innovative solutions due to its combination of academic and industrial expertise, which was well received. We anticipate a full call for proposals within the next few months, and we are hence already exploring possible concepts via TEAM-A funding. Metaboards: A small start-up company working on metamaterials. QQ and UoE have independently made contact with the company over the last couple of years, and are now in discussion with them over possible DASA projects or other forms of collaboration – early stages. Key partners include Theta Technology (SME), The University of Warwick, PepsiCo and The University of Exeter. A key point to note is the University of Warwick project led on to a fully funded EPSRC grant and the PepsiCo project has led to the funding of a Research Fellow for several years and a PhD Studentship.

Innovation projects	7 projects funded since the beginning of the programme. During this last year of the programme our innovation fund will be focusing on investing in staff contract extensions and customer focused challenges. Ultimately we will be looking to use this fund to support the bringing in of future investment for TEAM-A.
Website articles / marketing	9 articles published by our Research Fellows and 1 by TEAM-A's first summer Intern, details can be seen here.
Staff development	
Training courses attended	4 Research Fellows have attended The Royal Society's Media and Communication Skills course. Project administration & 1 Research Fellow have received certification by the Association for Project Management.
Employment & Secondment	Research Fellows are supported through mentorship, specialist & general training interests. For example, IET career mentorship has been taking place for the past annum (Dr Alexander Boyland of SPI Lasers) to guide TEAM-A Research Fellow A.May through the application procedure for chartered engineer (CEng) status. All 3 of TEAM-A's QQ based Research Fellows have been offered full time employment at QinetiQ. We have ensured the continuation and completion of TEAM-A work by keeping two of them on the project one day per week (one until Dec'21; the other Sept'22). Additionally, during his TEAM-A contract, Research Fellow J.Hamilton was seconded as a consultant to another QinetiQ based project for 8 weeks.
Progress to self-sufficiency' Additional revenue generated	TEAM-A have received additional funds from PepsiCo & NATEP. We are in contact with multiple customers and responding to prospered customer challenges with a view to securing future work and income. Regular benefits realisation meetings & tracking are ongoing to ensure that our remaining funds are used strategically. These include the engagement of QinetiQ Business Development Staff (e.g. K Ashton, AS&P Head of Sales) and J Bambrough, QinetiQ's Head of Concepts & Services, who are reviewing business cases for some of the TEAM-A technologies.